LEAP and TEM of Nitronex GaN HEMTs

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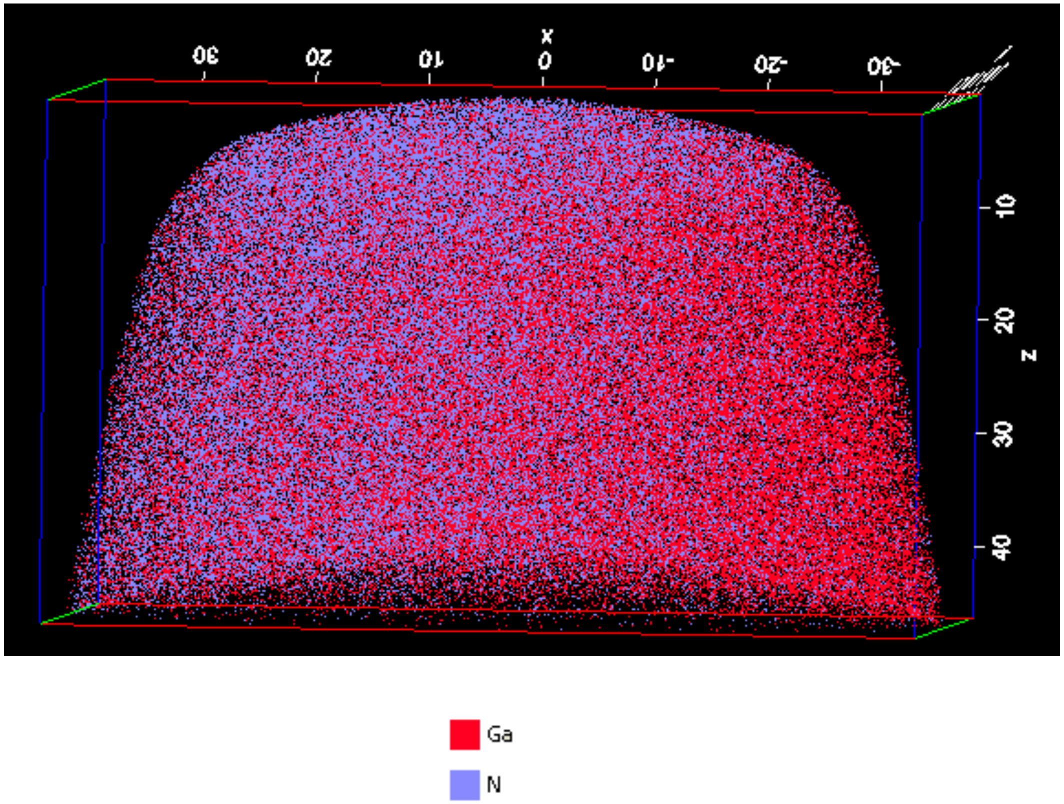
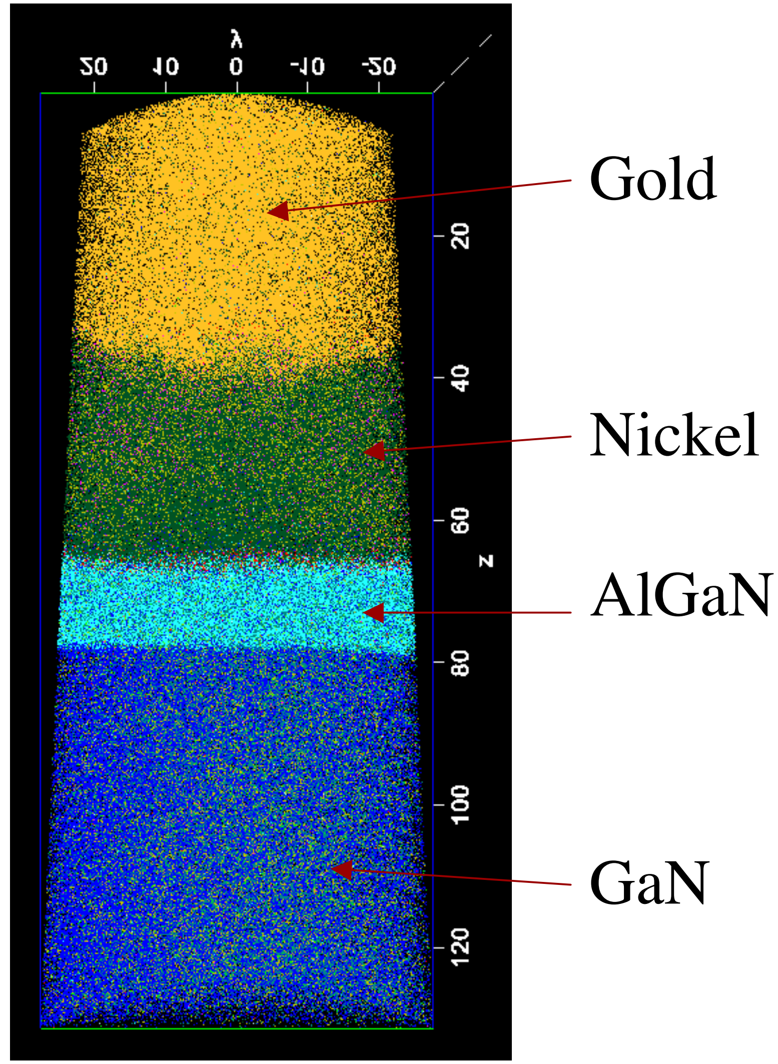
Last Review: Reported First LEAP analysis of bulk GaN

- Demonstrated that GaN can be analyzed by LEAP despite low conductivity
- 78,000,000 Atoms collected from this run
- LEAP reconstruction under gate in bulk GaN

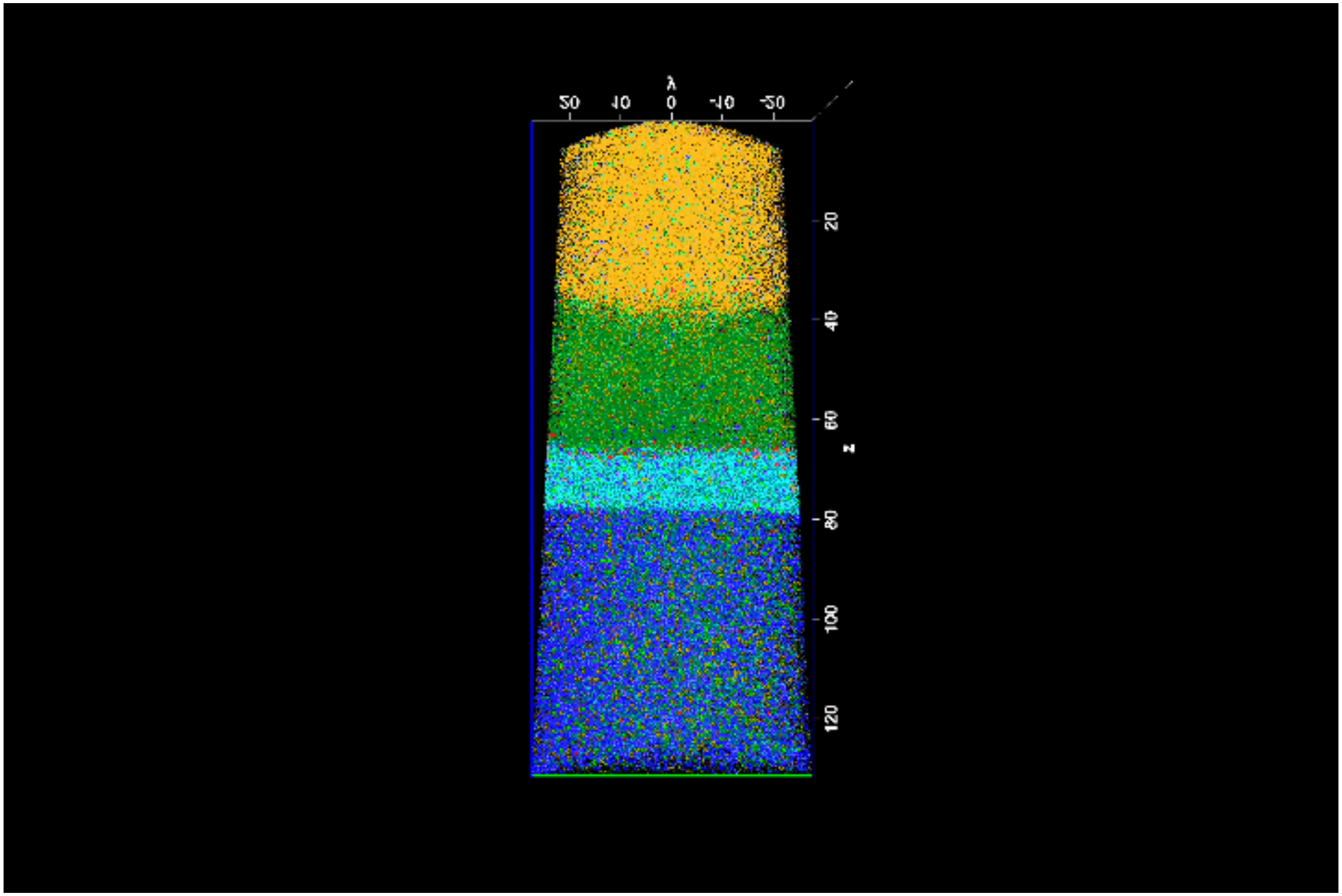


New LEAP Analysis

- LEAP reconstruction of gate region
  - Gate metal stack
  - Gate/Semiconductor interface
  - AlGaN/GaN interface

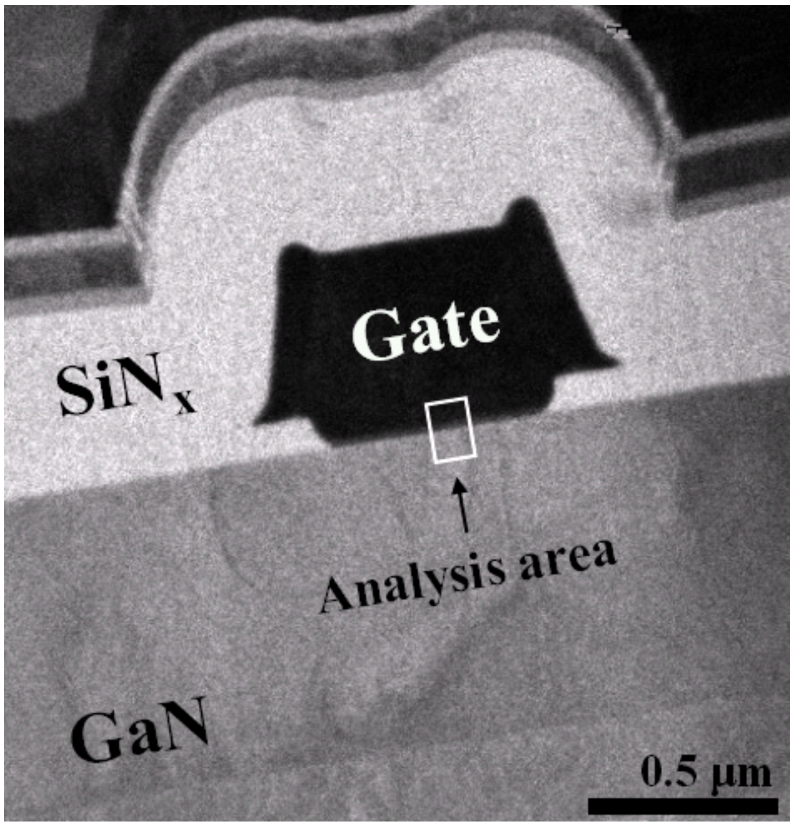


LEAP Reconstruction

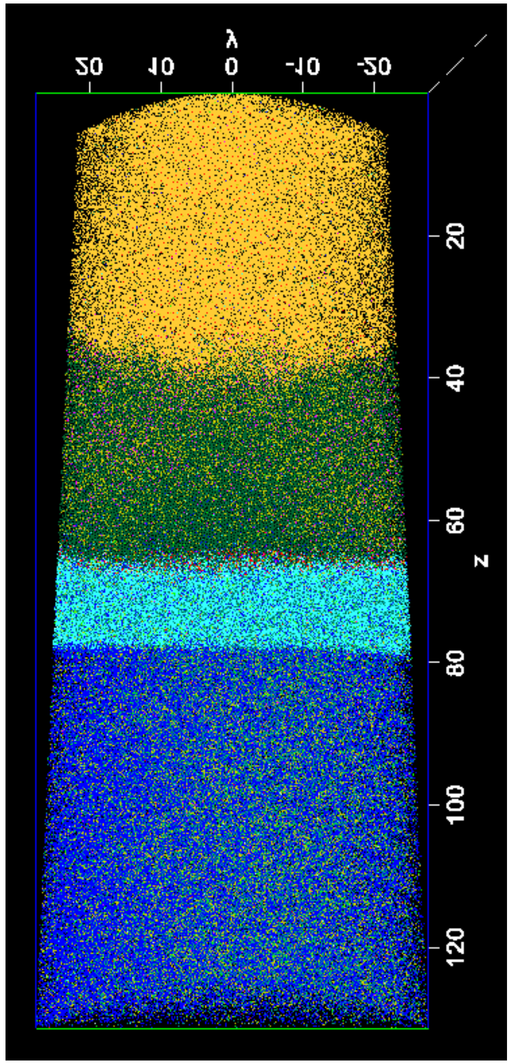


TEM and LEAP Comparison

- TEM



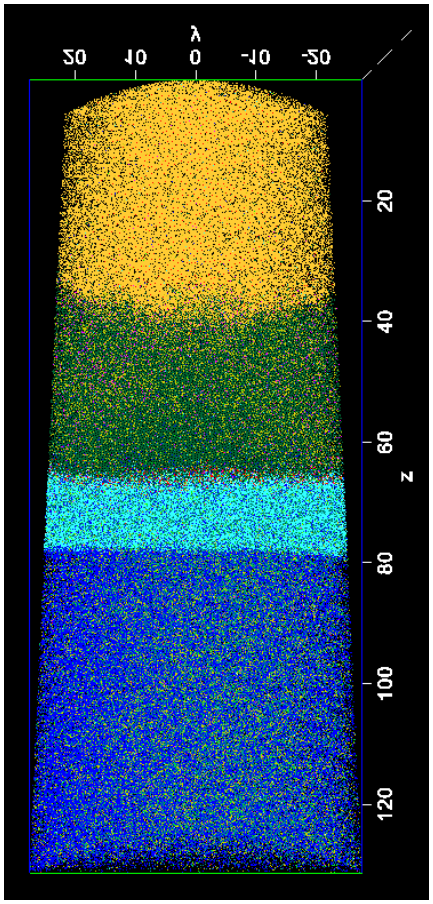
- LEAP



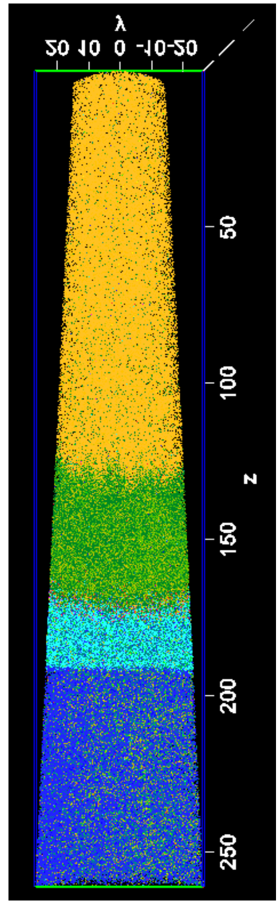
Reproducibility

- 3 completed LEAP runs of the gate region

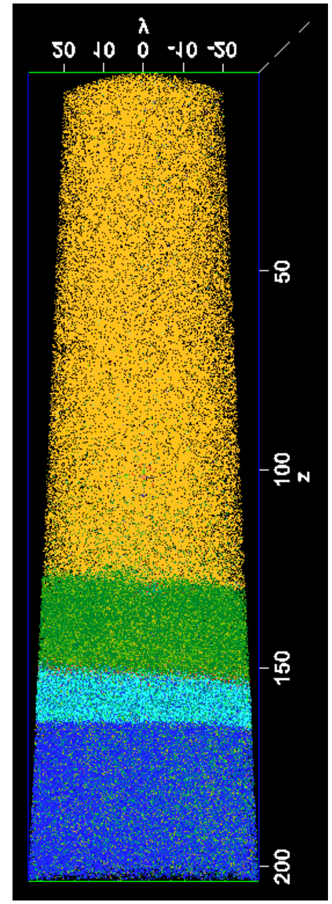
•2M28



•2M30



•2M36

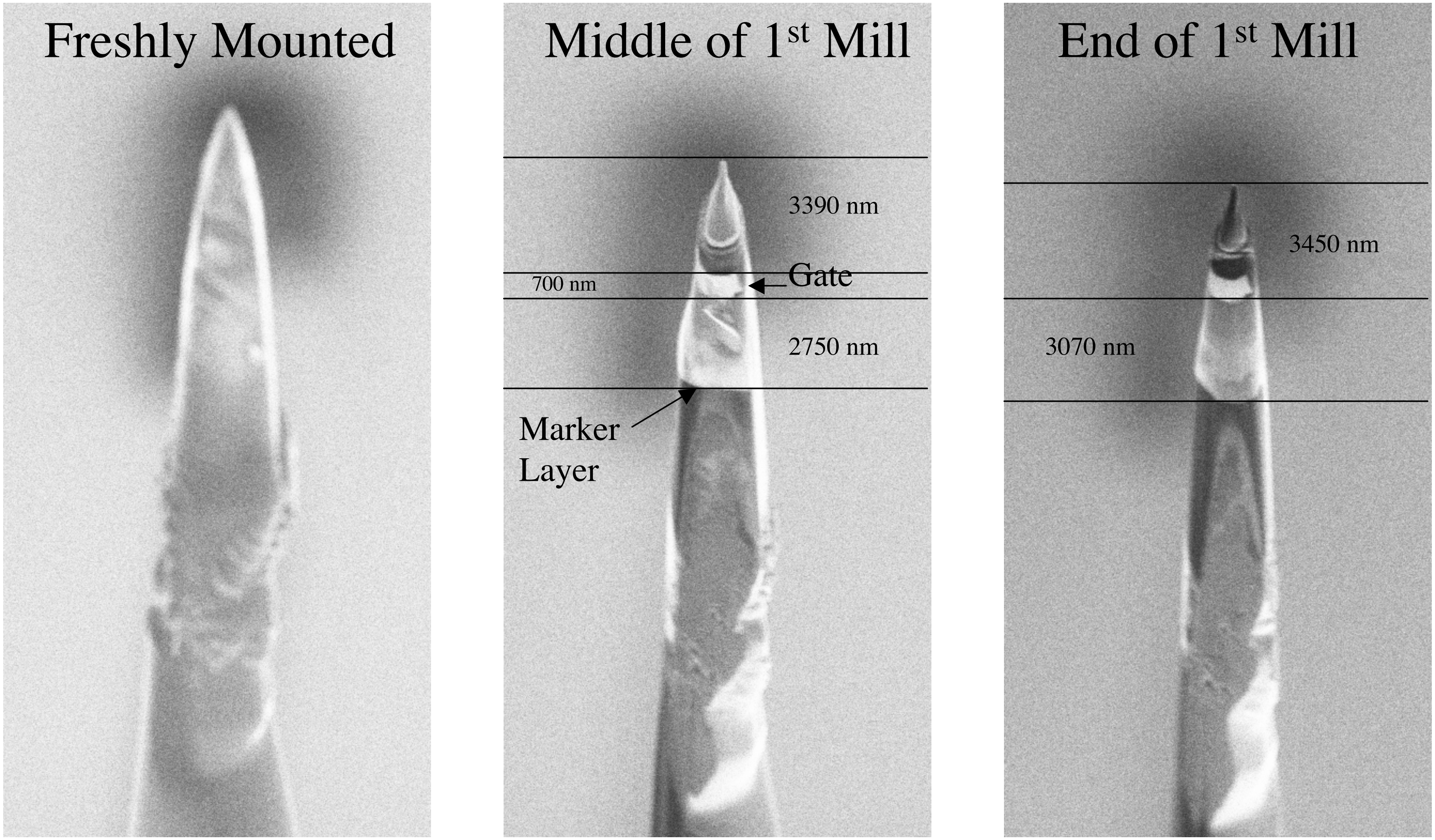


Making Site Specific LEAP Tips

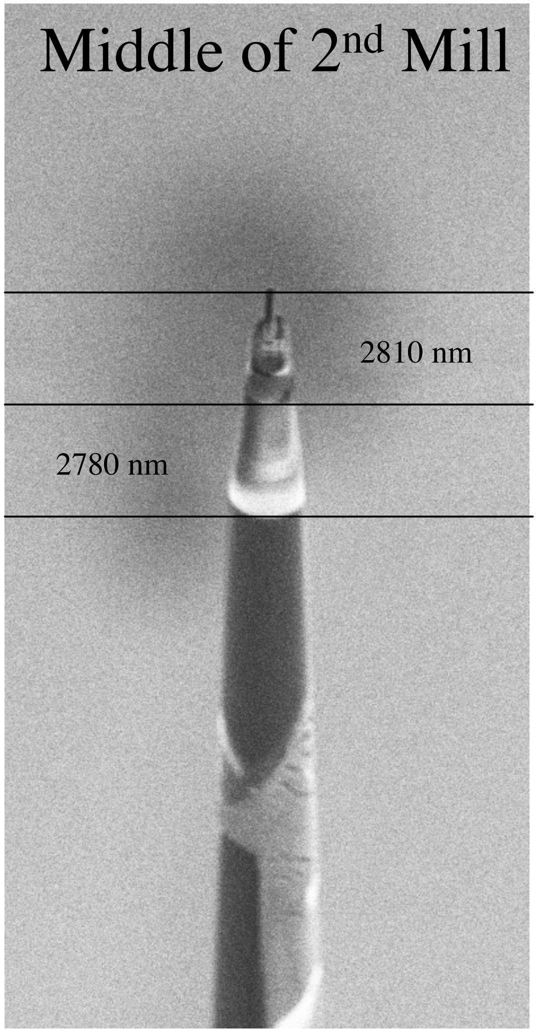
- Possible to make site specific tips
  - Areas of interest are not random but purposely chosen

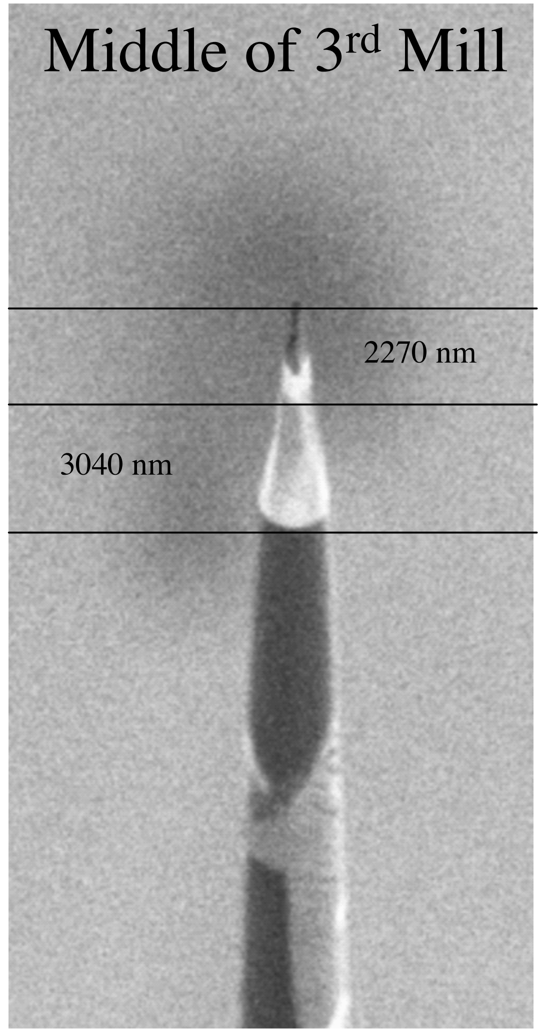
- Procedure:
  1) Find area of interest during mill
  2) Find a permanent marker layer on LEAP post
  3) Measure distance from marker to the feature
  4) Measure distance from feature to the end of the tip
  5) Mill tip and simultaneously record these measurements
  6) When tip is ~100-500 nm from feature, stop

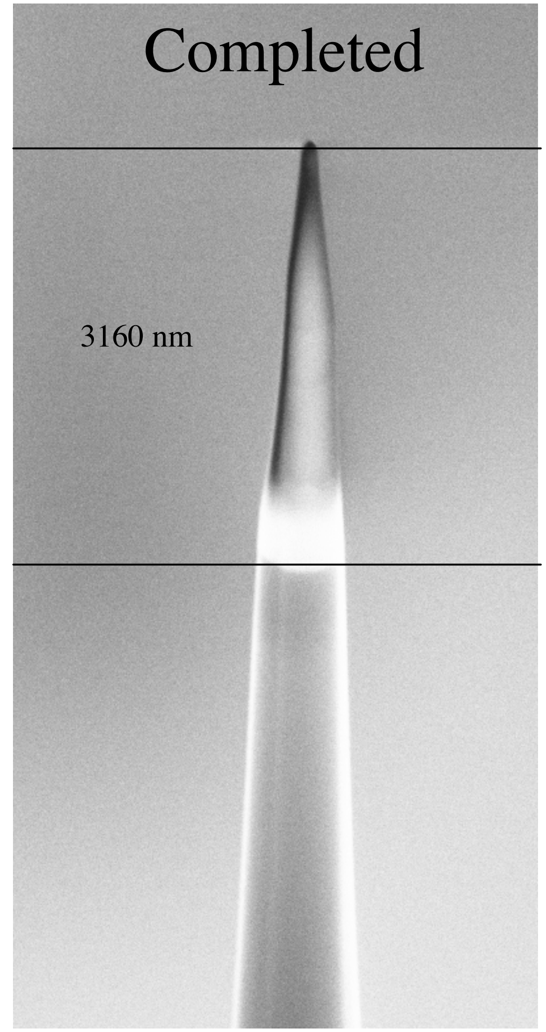
Making Site Specific LEAP Tips



Making Site Specific LEAP Tips

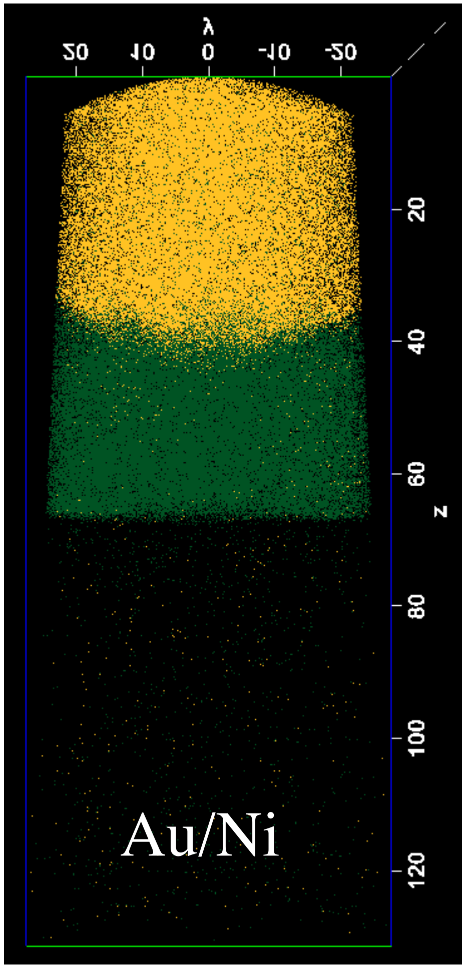




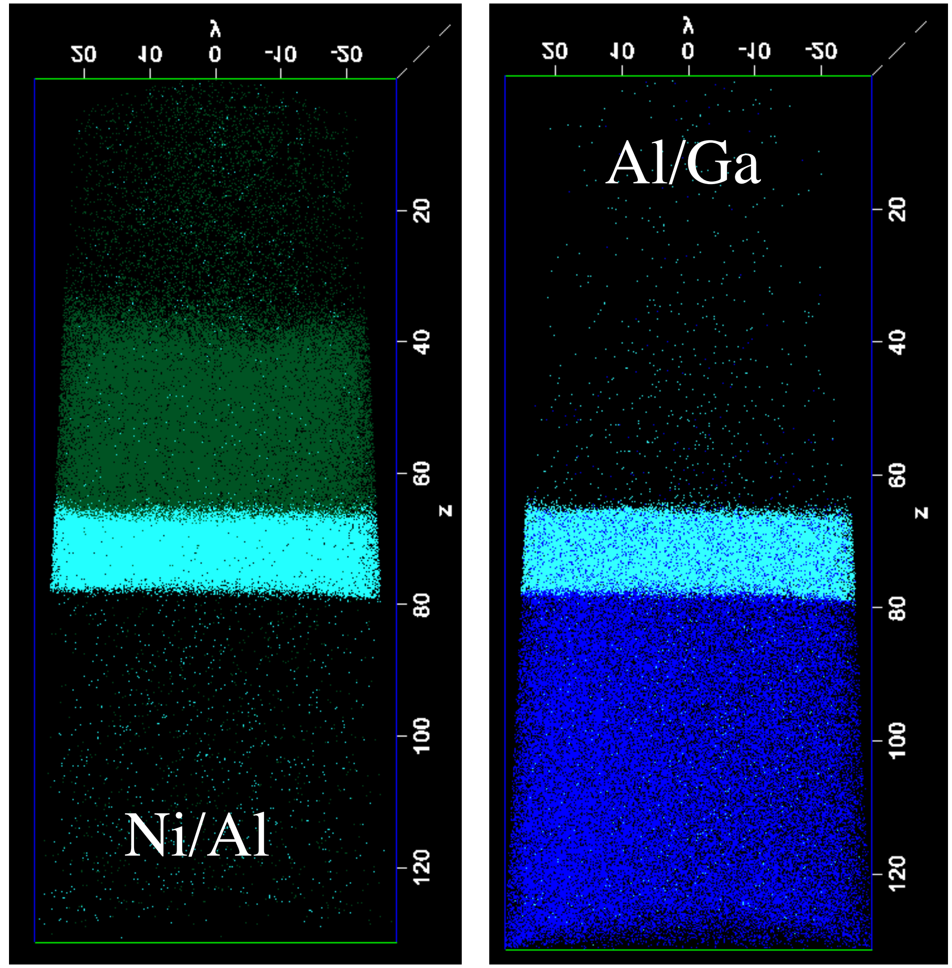


Interfacial Curvatures

- Diffuse

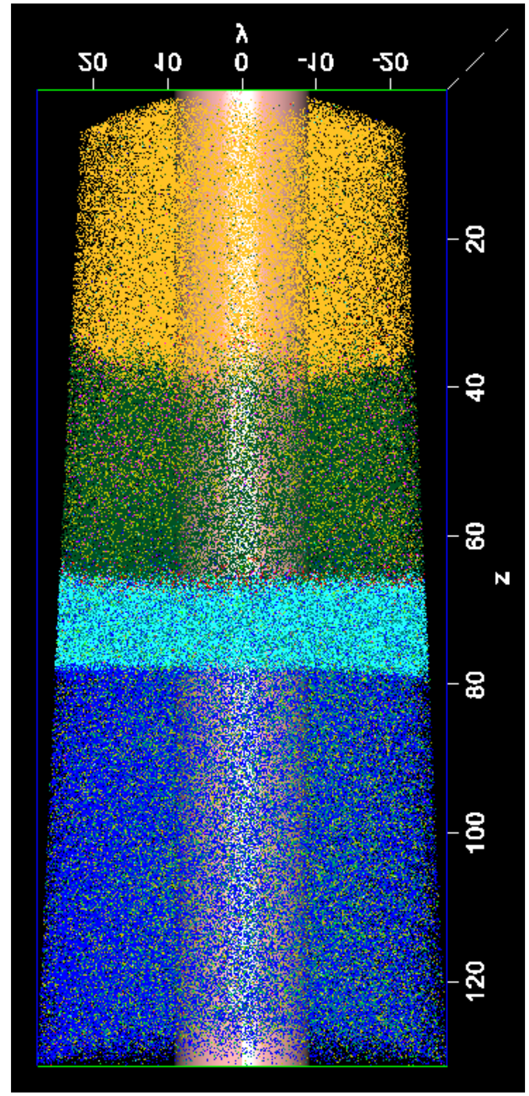


- Smooth

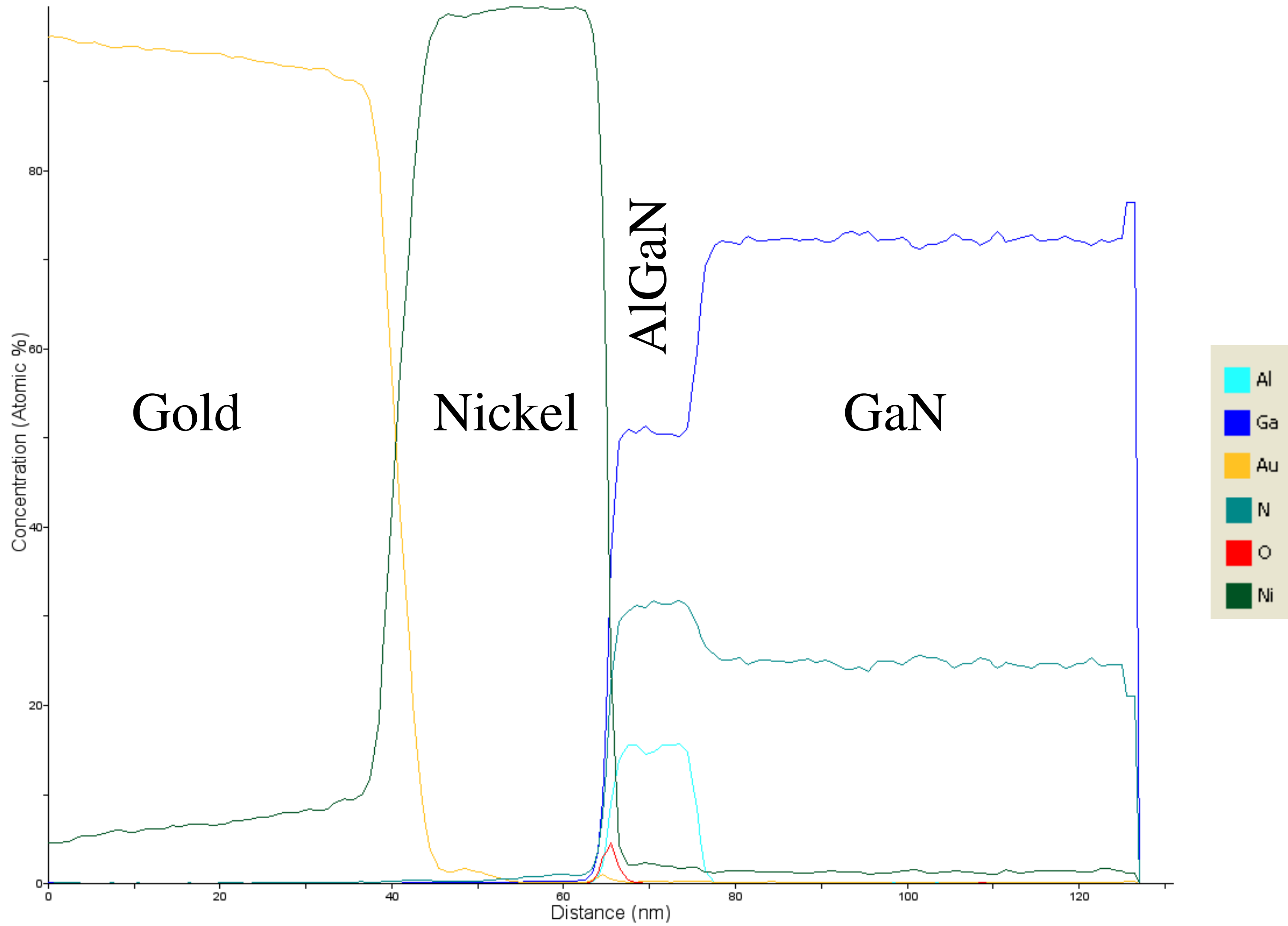


Analysis Cross Section

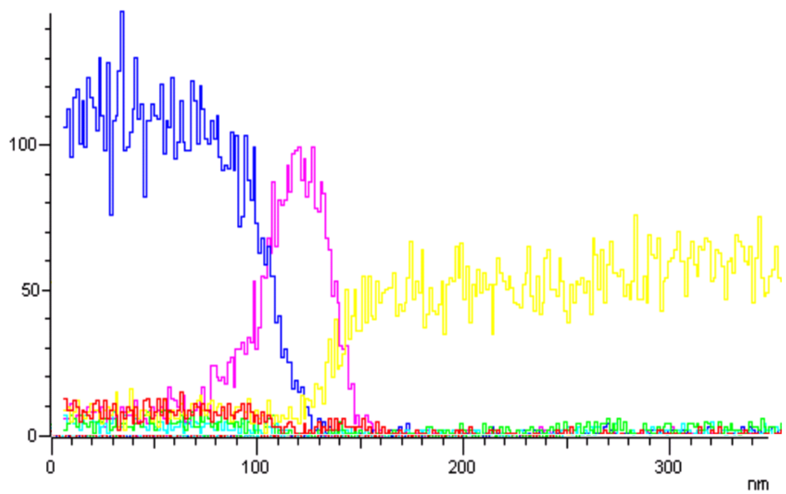
- Use data pipe to collect information
  - Analysis occurs along the length of the pipe and across the cross sectional area



1-D Concentration Profile



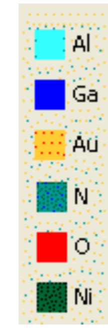
Comparison between STEM and LEAP Analysis

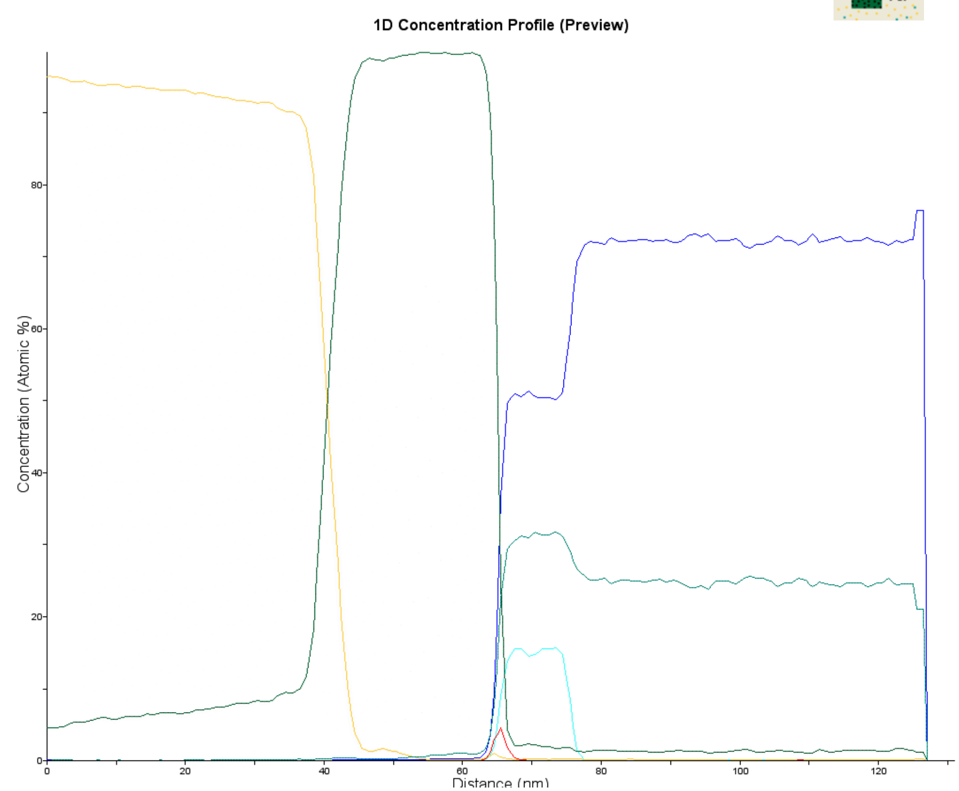


- STEM

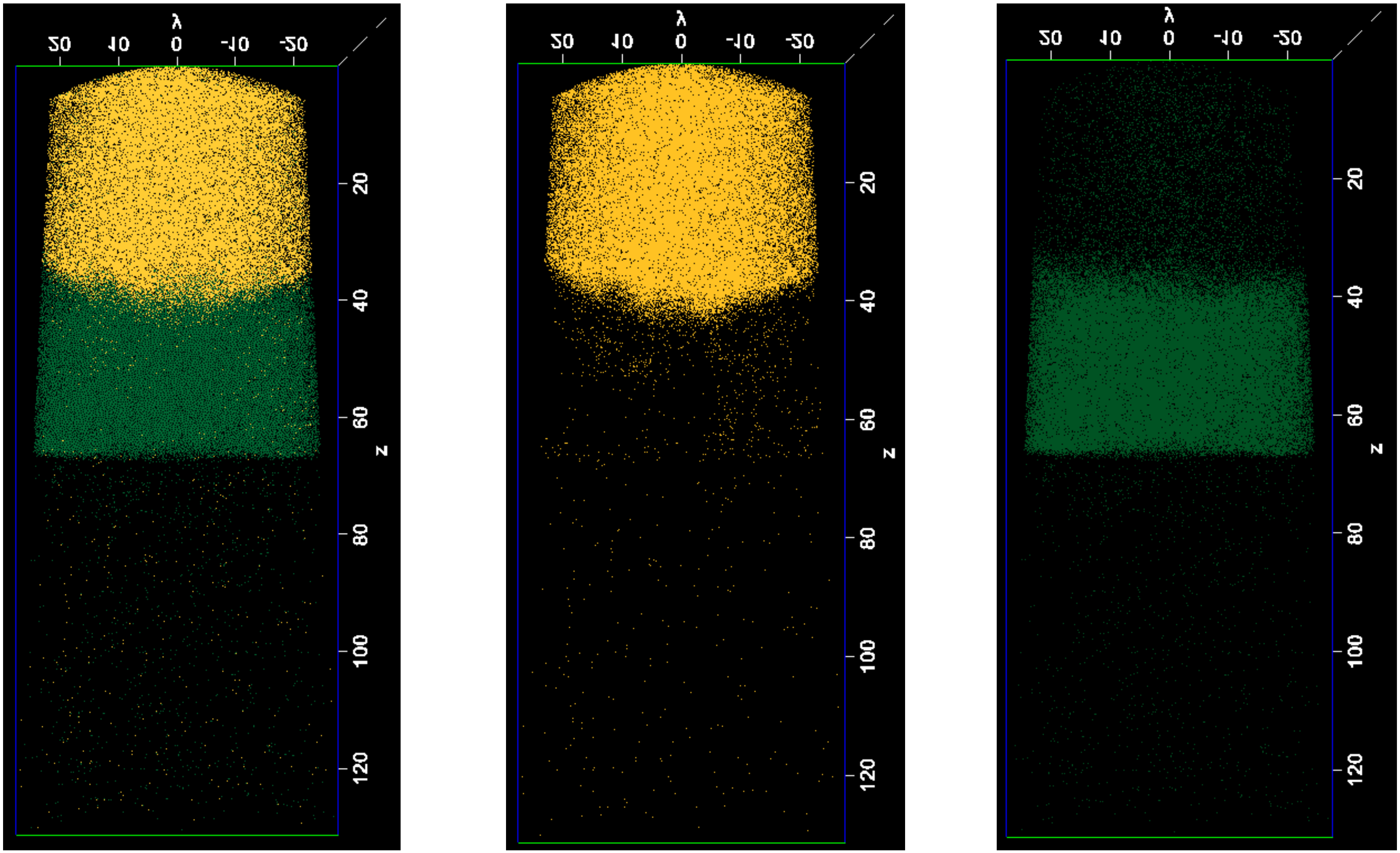
Gold
Nickel
Gallium
Aluminum
Nitrogen
Oxygen

- LEAP

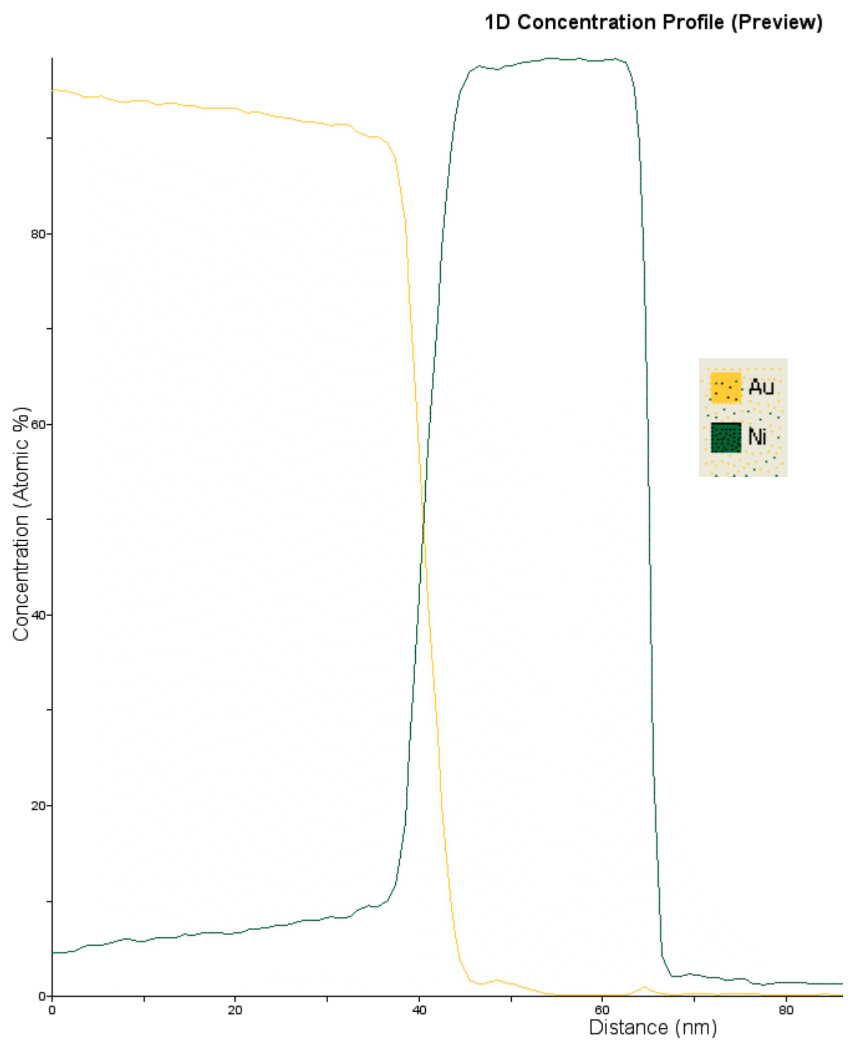


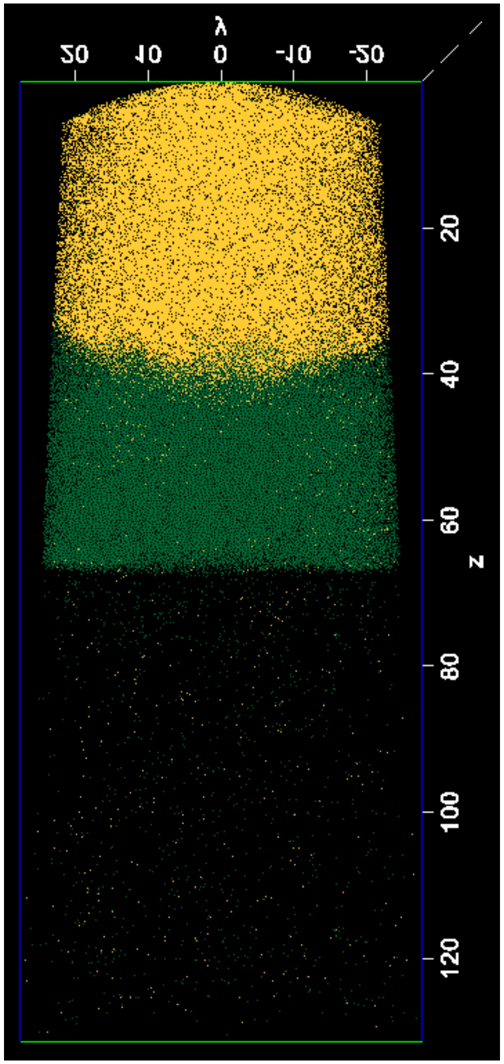


Gate Metal Diffusion Couple



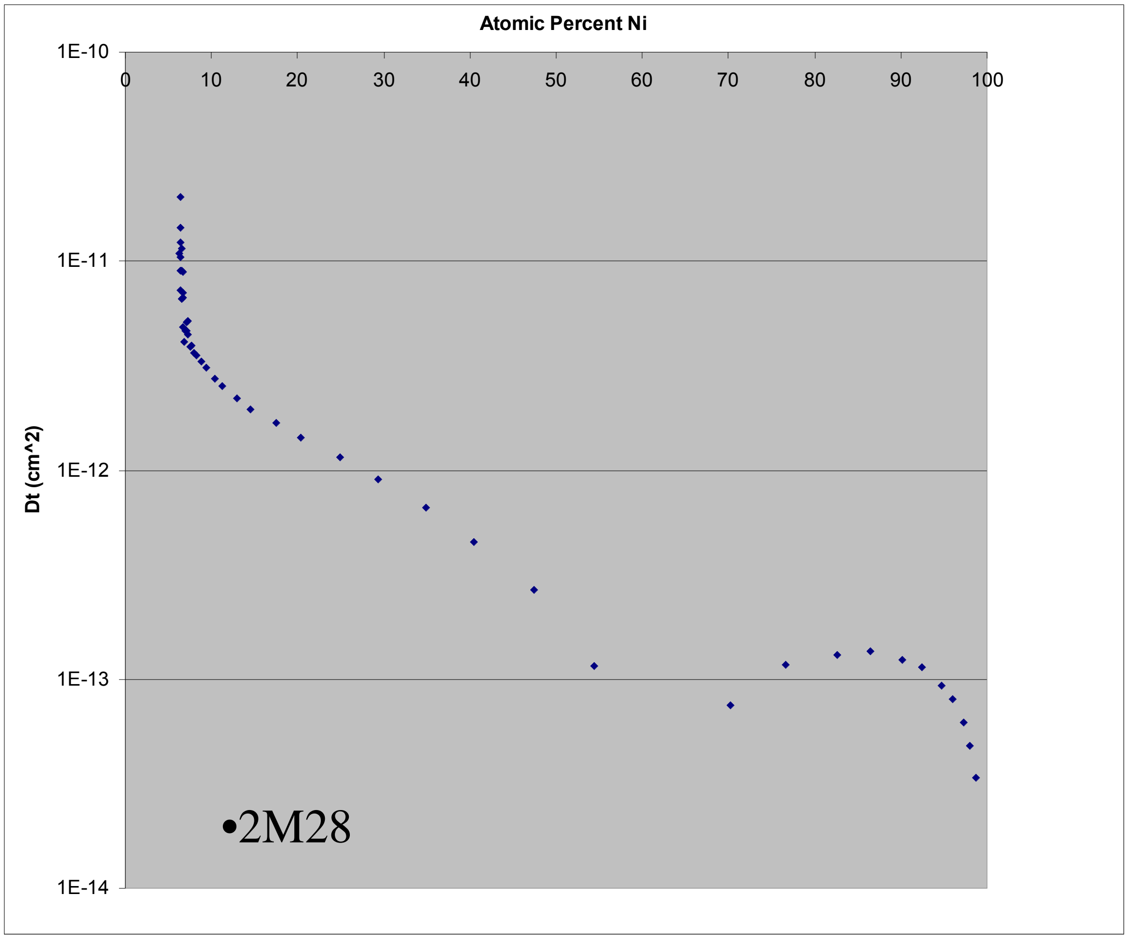
Diffusion Profile

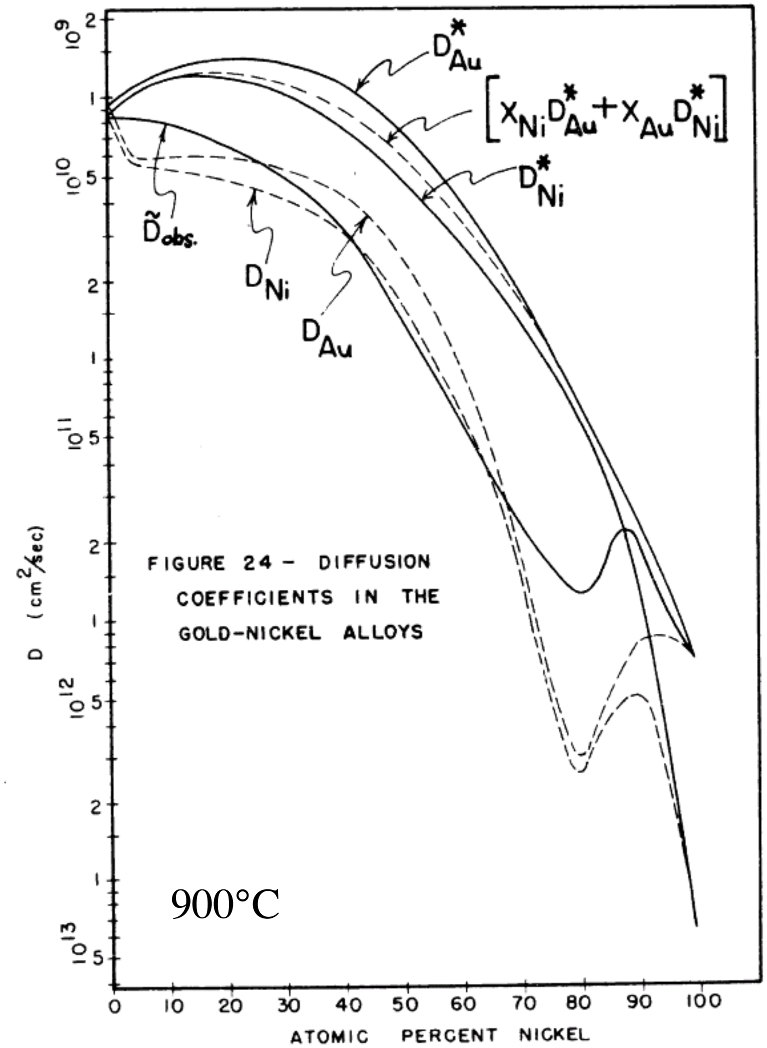




Comparing Diffusivity Values

- Boltzmann-Matano Method

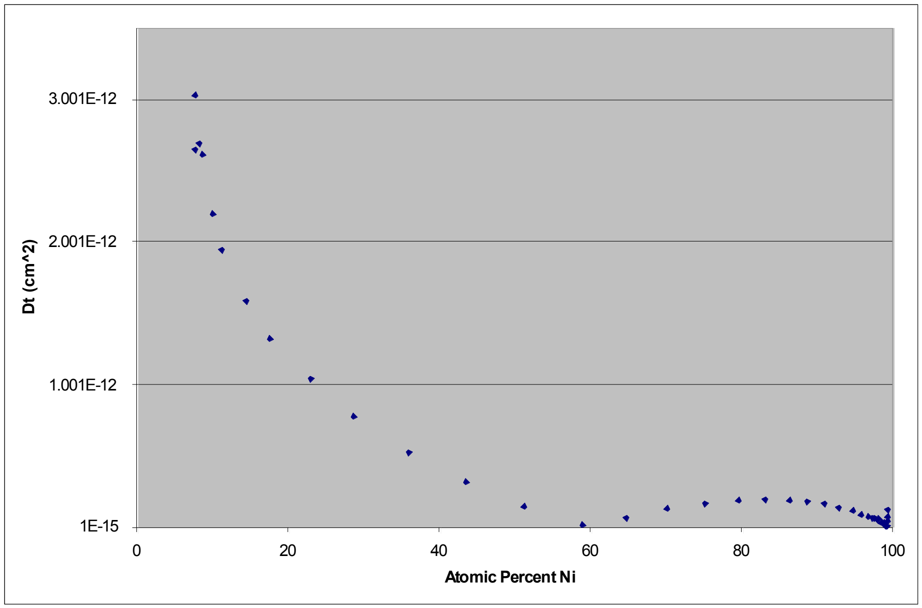




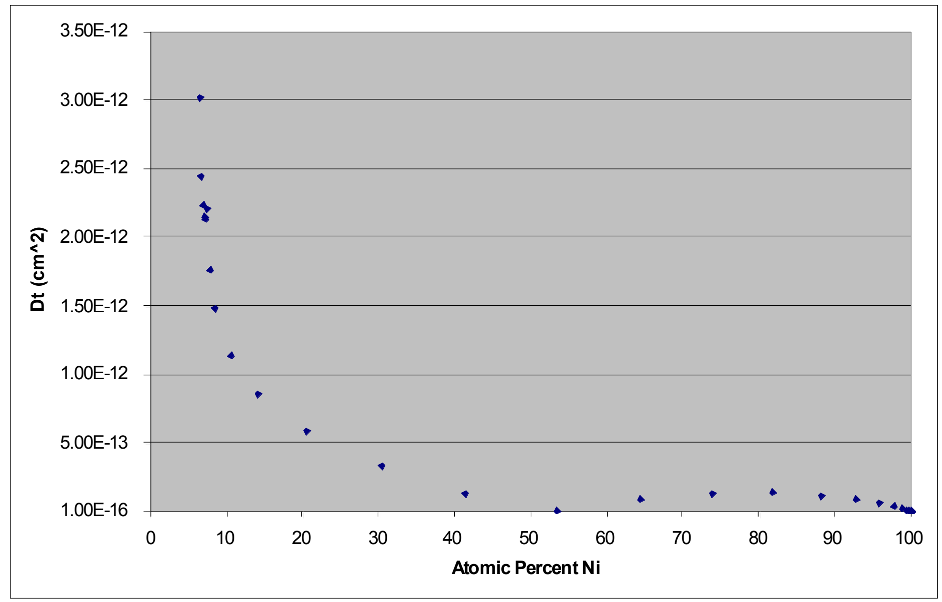
J. Reynolds, Ph.D. Dissertation, Diffusion in Gold-Nickel Alloys

Diffusivity Product Curves

- 2M30

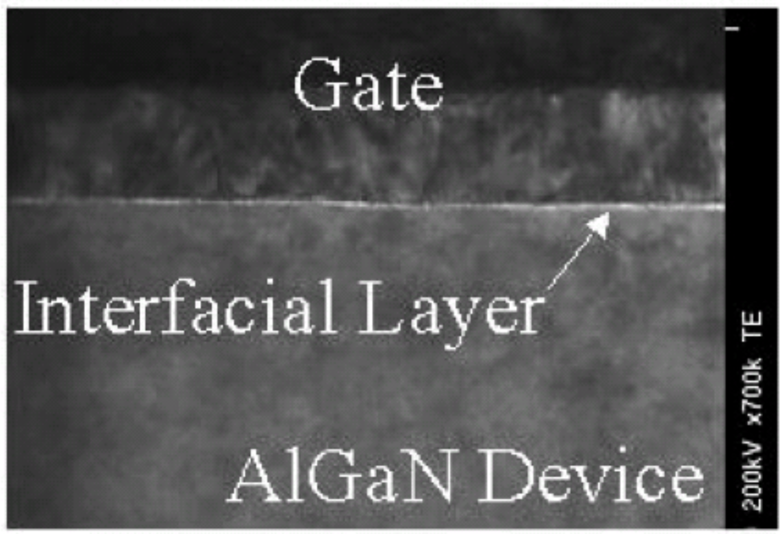


- 2M36



Interfacial Layer Analysis

- Nitronex has reported the presence of an interfacial layer between the gate and AlGaN

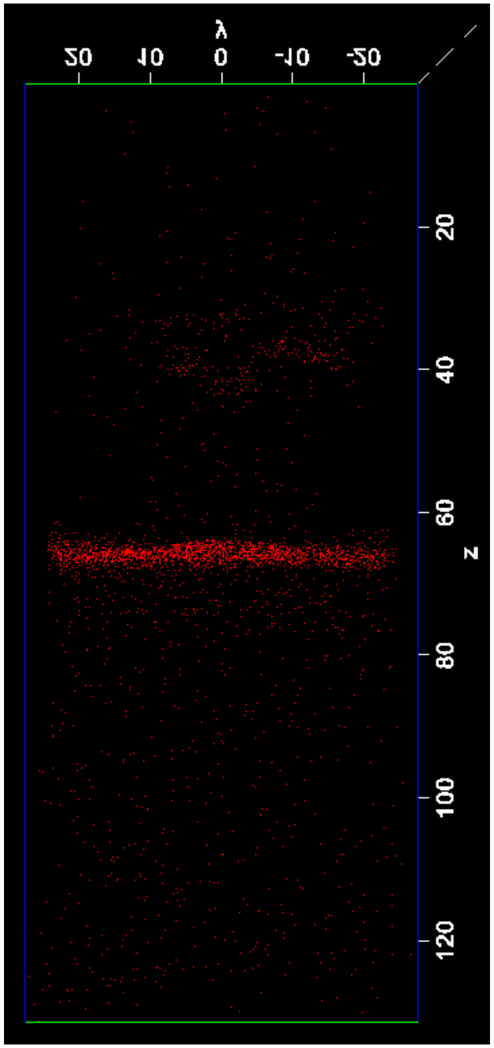


S. Singhal, et al., GaN-on-Si Failure Mechanisms and Reliablility Improvements

- LEAP analysis has been used to characterize this layer

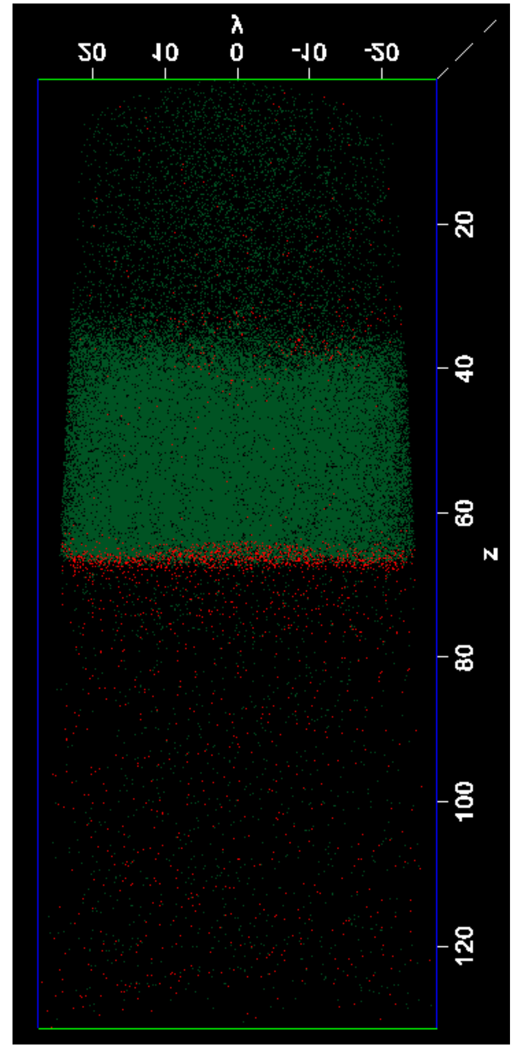
LEAP of Interfacial Layer

•Oxygen Layer



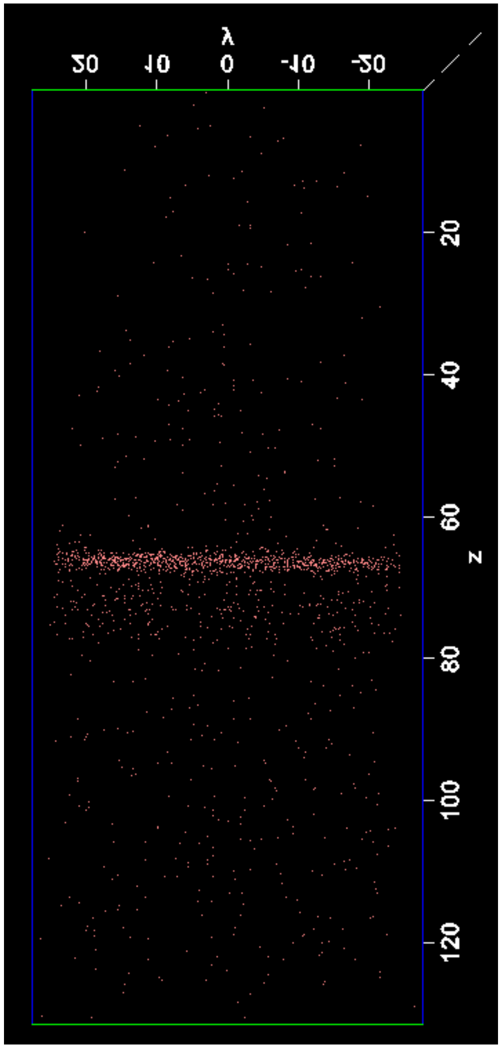
- Oxygen layer present between Ni and AlGaN
- AlO_x and NiO_x were also detected
- No GaO_x deteched

•Oxygen/Ni interface

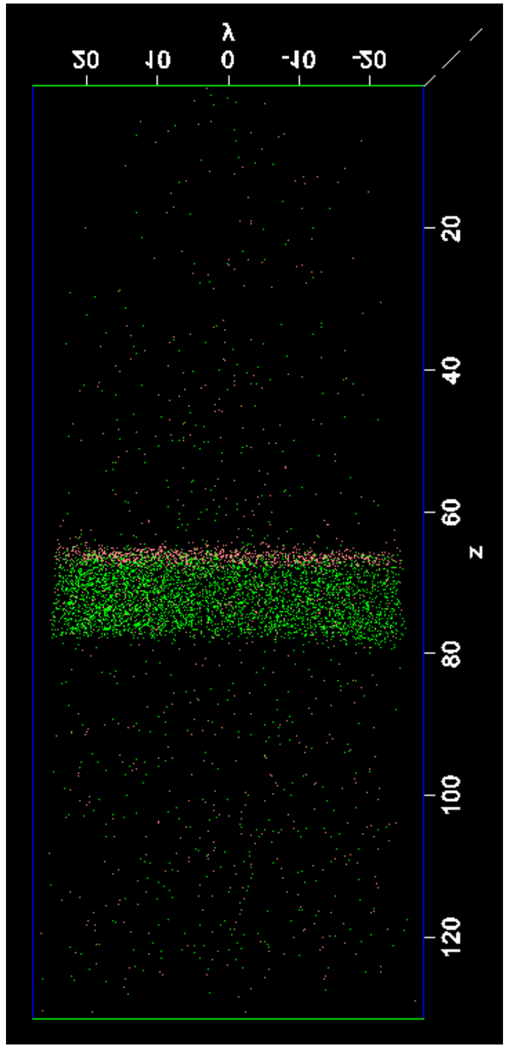


LEAP of Interfacial Layer

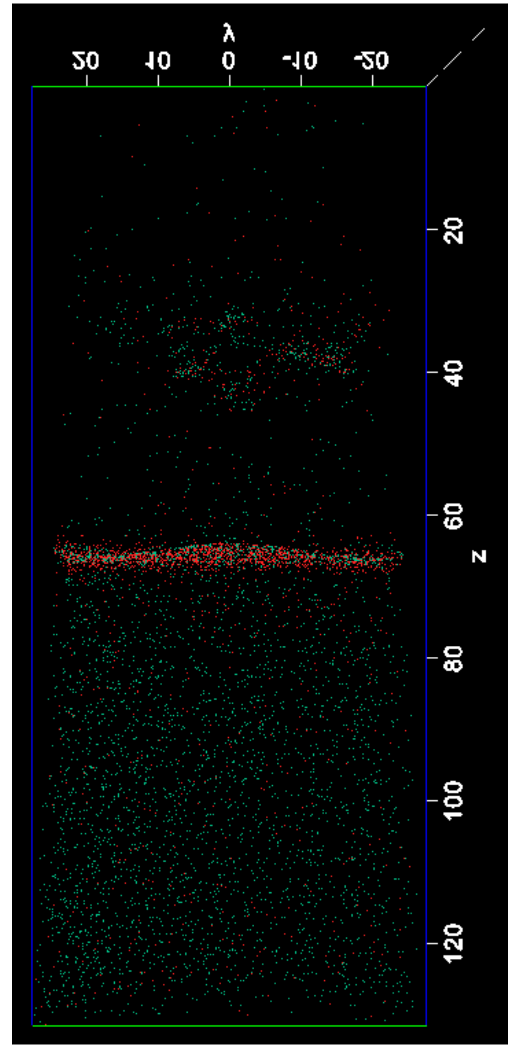
•AlO_x Layer



•AlO_x/AlN interface



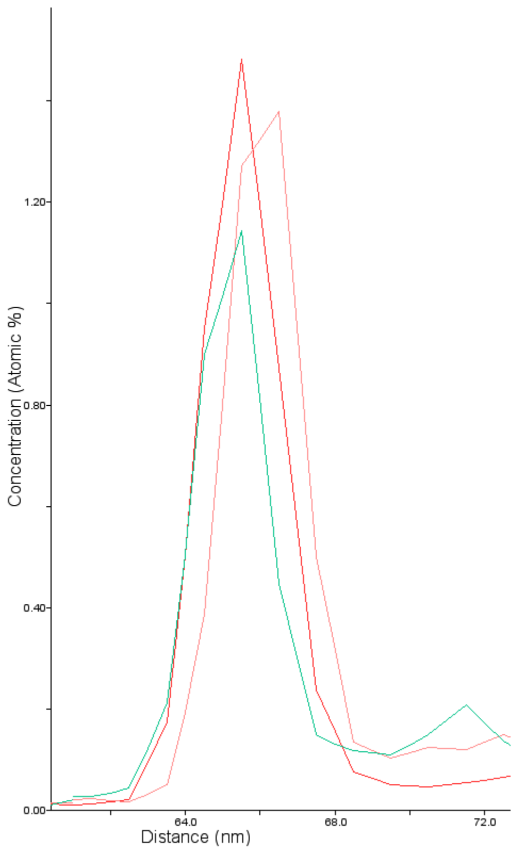
•NiO_x/O interface



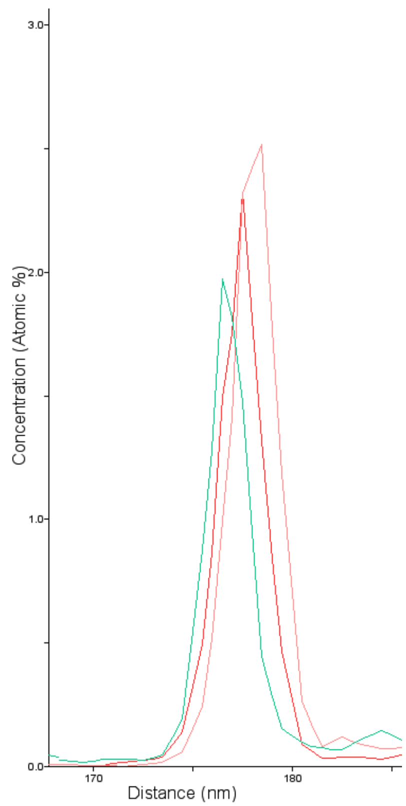
Interface Concentration Profiles

- Layers always appear in order of $NiO_x/O/AlO_x$ at interface

•2M28



•2M30



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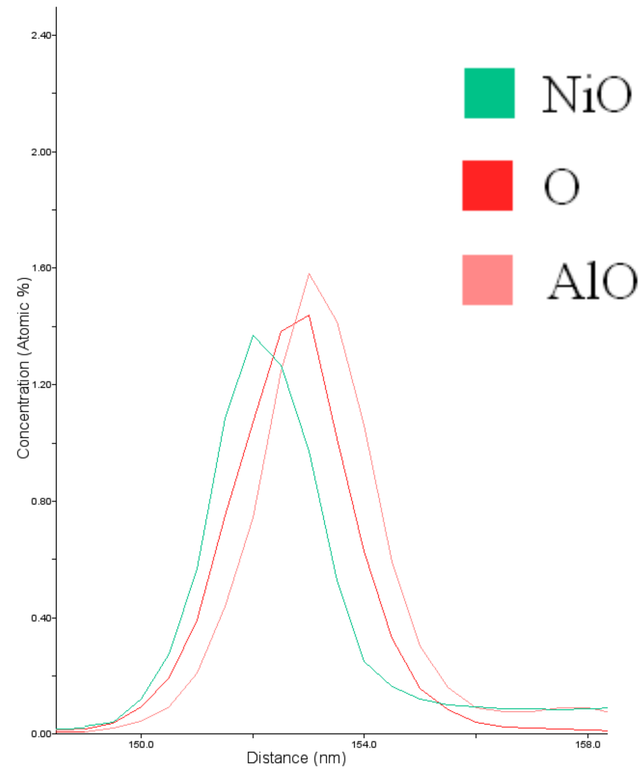
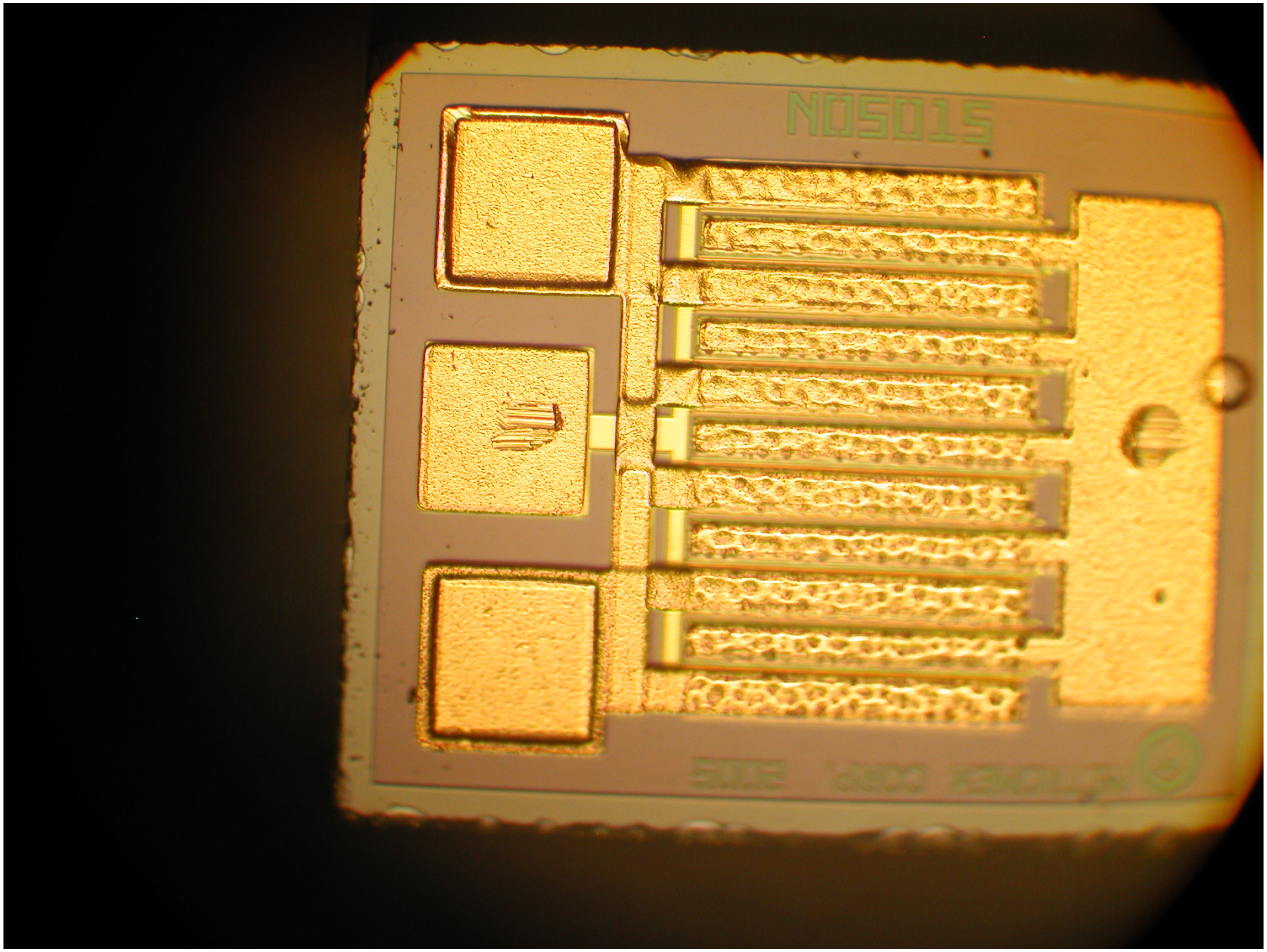


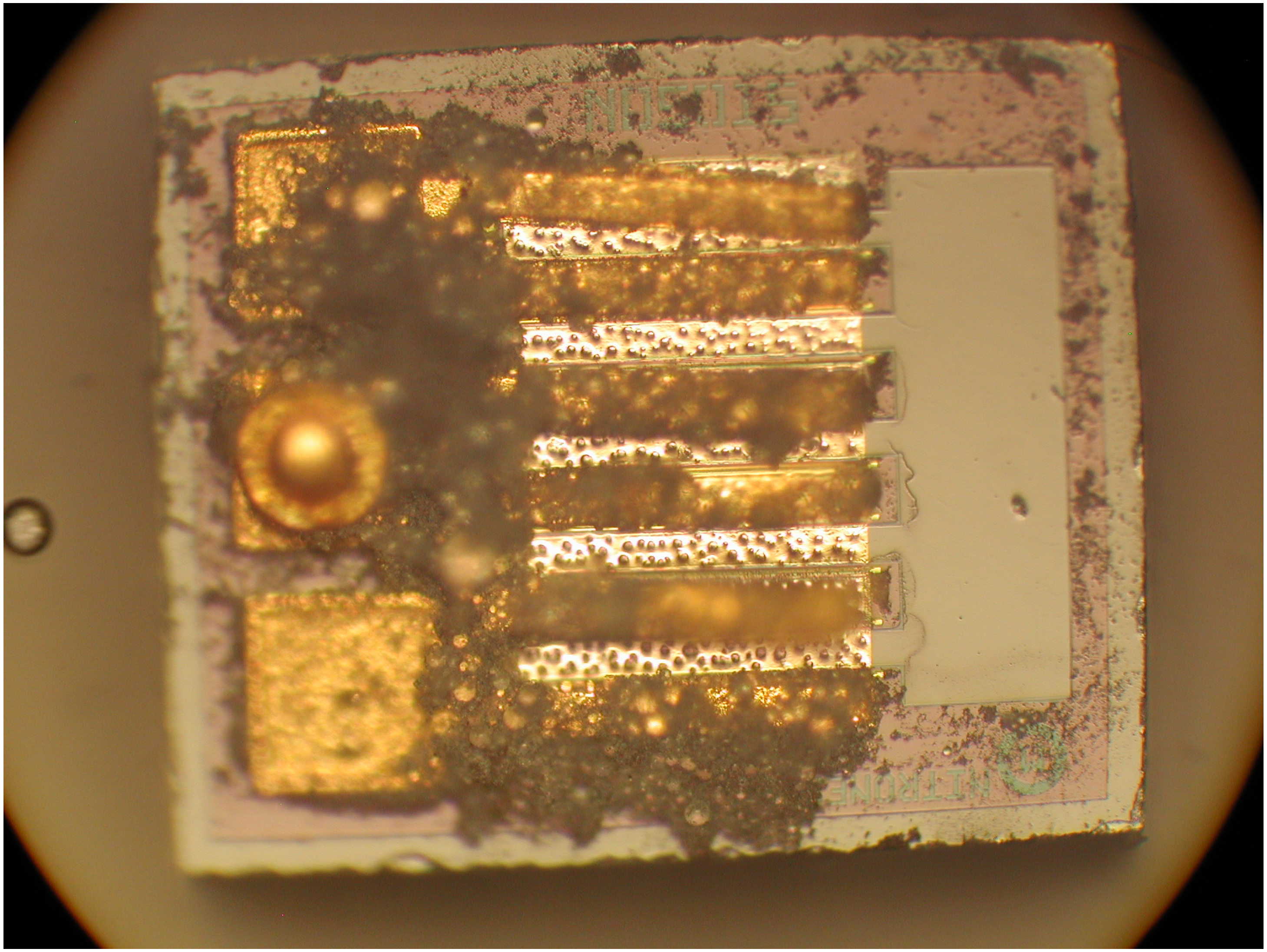
Deprocessing

- Virgin Encapsulated Device
  - Exposed to nitric acid for 116 hours
    - Some encapsulant remained on surface
  - Ultrasonicated in nitric acid for 1 hour
    - Removed most remaining encapsulant
- Process completely removes source and drain metal contact stacks
- SiN_x protects the surface from nitric exposure
  - Gate metal protected

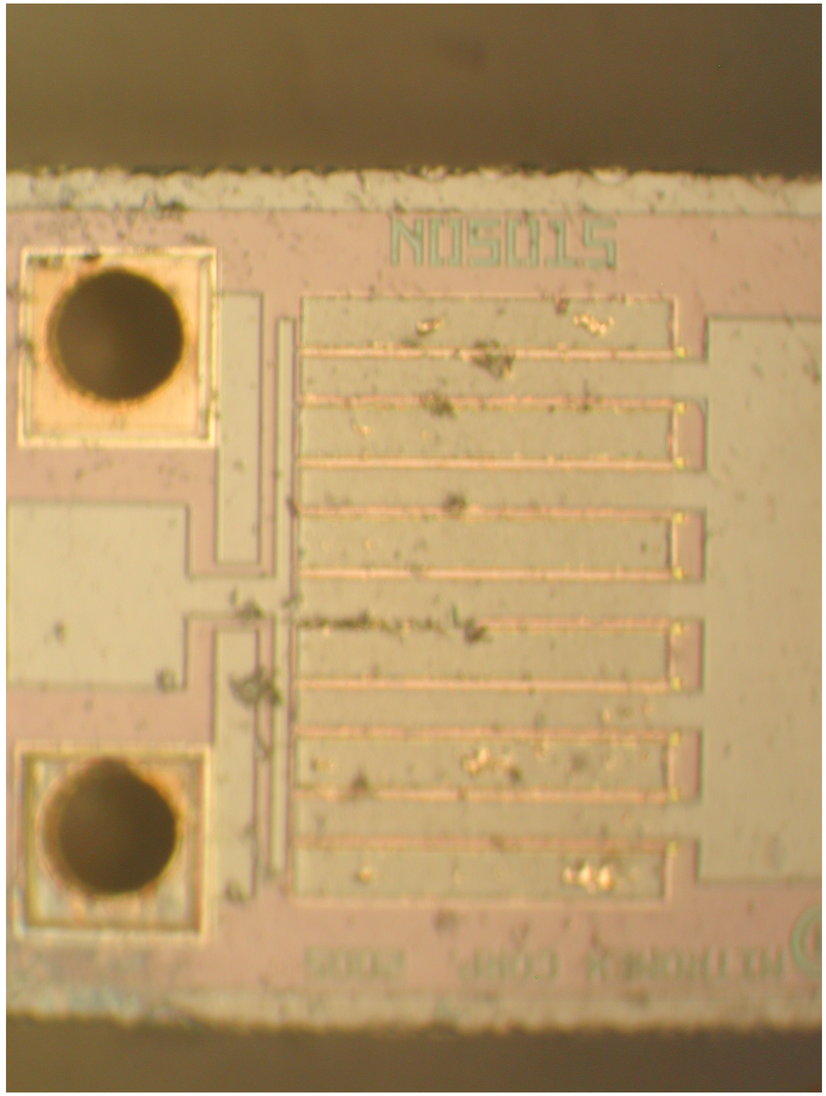
Non Encapsulated



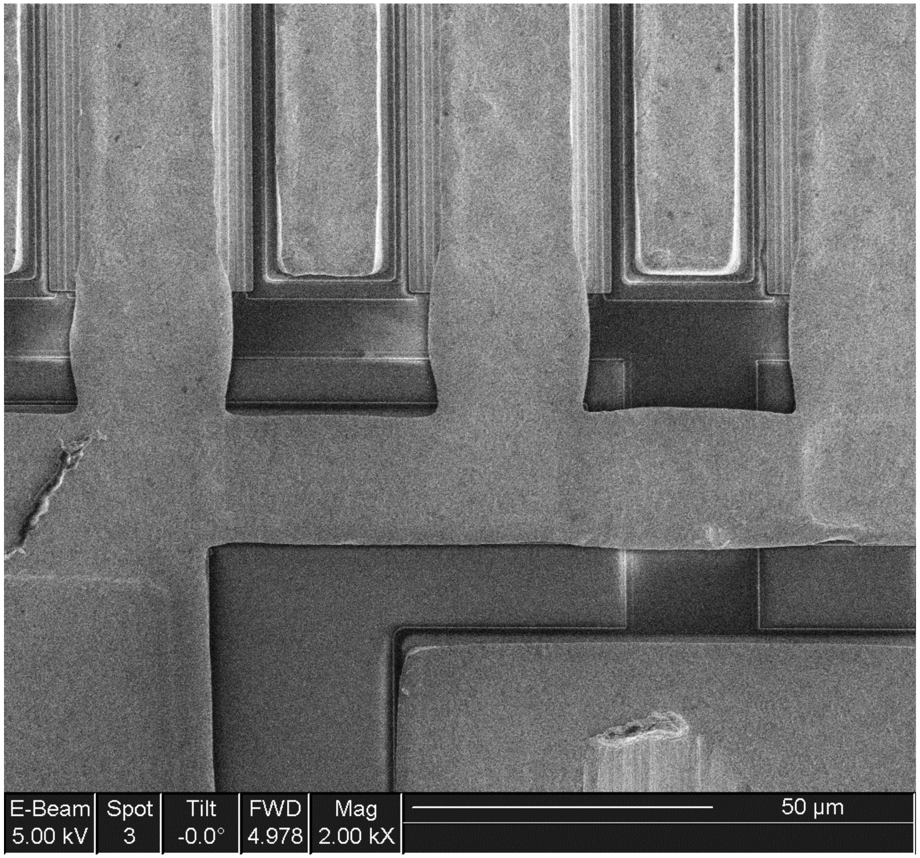
After Nitric Exposure

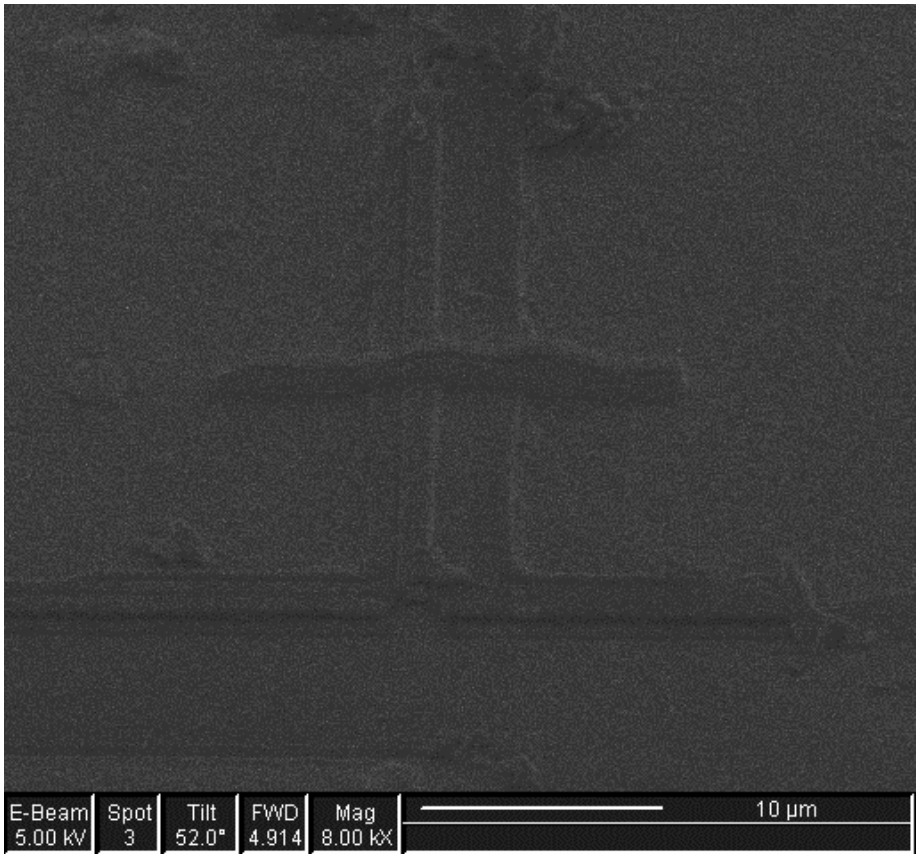


After Sonication

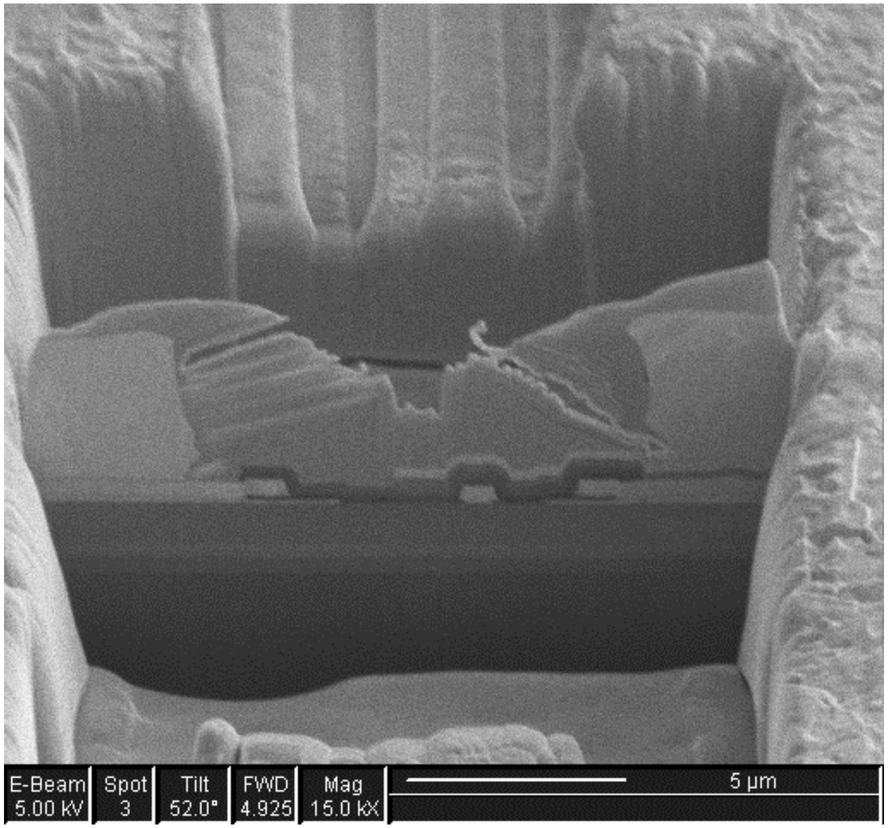


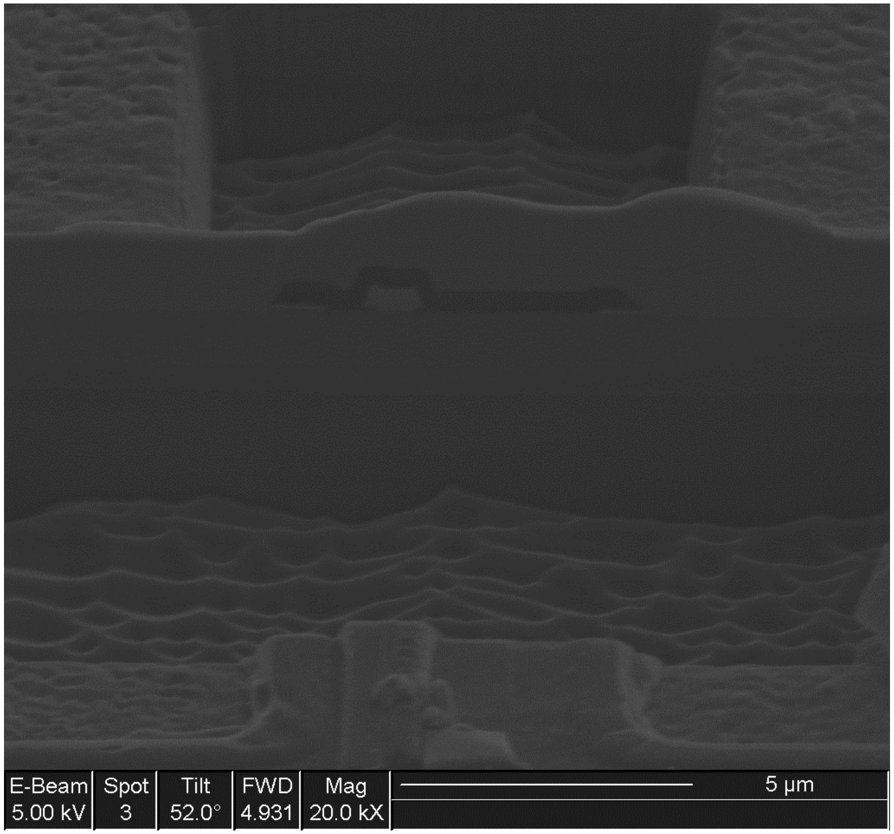
SE-SEM Images





SE-SEM Images



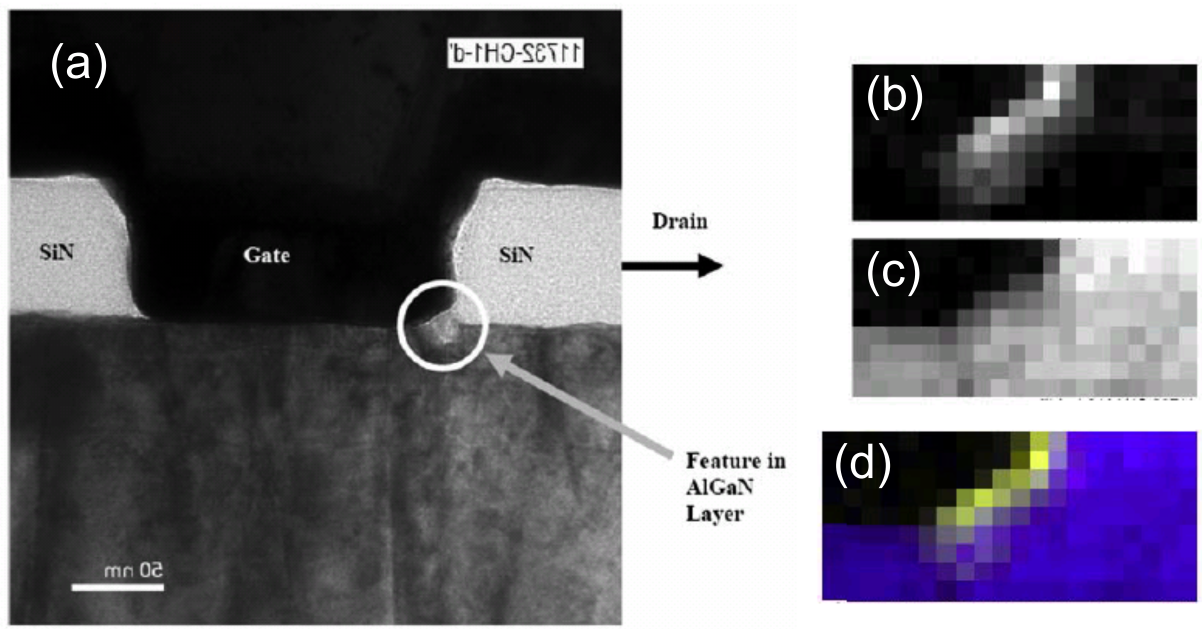


Work in Progress

- In-plane stress experiments
  - Stress applied to Nitronex epi-structure wafers
    - Courtesy of Edwin Piner
  - Utilizes quartz bending jig
    - No applied bias or electric field
  - Two wafer thicknesses
    - Standard (as shipped)
    - Ultra-thin
      - Allows higher stress states due to greater curvature
- Outcome?
  - Stress required to produce defects
  - Effect of stress on diffusivity of Si and other intefacial reactions

Previous Studies - Conway

- DC testing
  - 3000 hours
  - T_{Ch} = 172°C
  - V_{DS} = 30 V
  - I_{DS} = 40 mA
  - Air

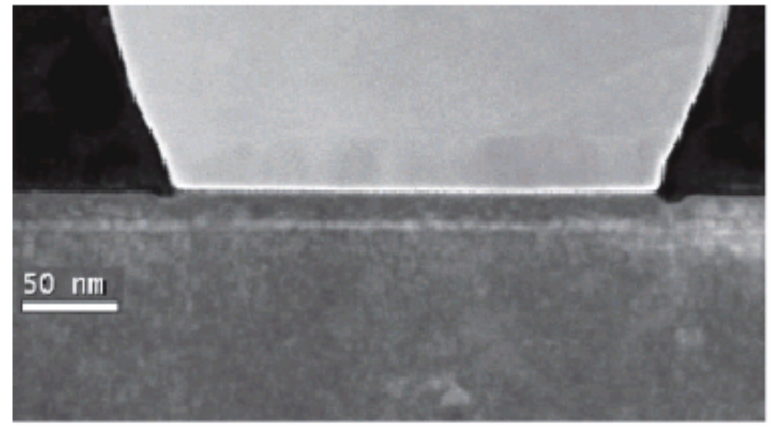


(a) XTEM micrograph of the reaction product
(b) EELS map of oxygen distribution
(c) EELS map of nitrogen distribution
(d) Combined EELS map of oxygen (yellow) and nitrogen (blue)

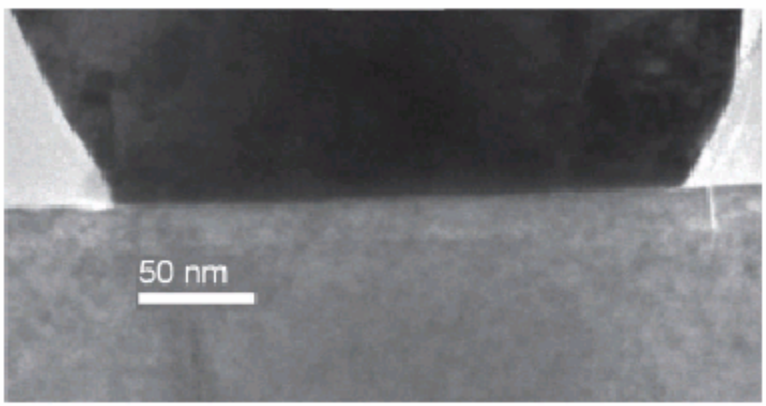
A.M. Conway, et al., CS MANTECH Conference. 99 (2007)

Previous Studies - Chowdhury

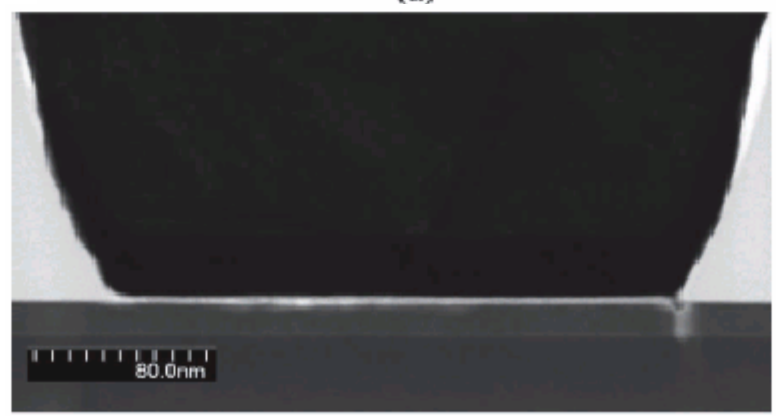
- DC testing
  - 1000 hours
  - T_{Ch} = 250°C, 285°C, 320°C
  - V_{DS} = 40 V
  - I_{DQ} = 250 mA/mm



(a)



(b)



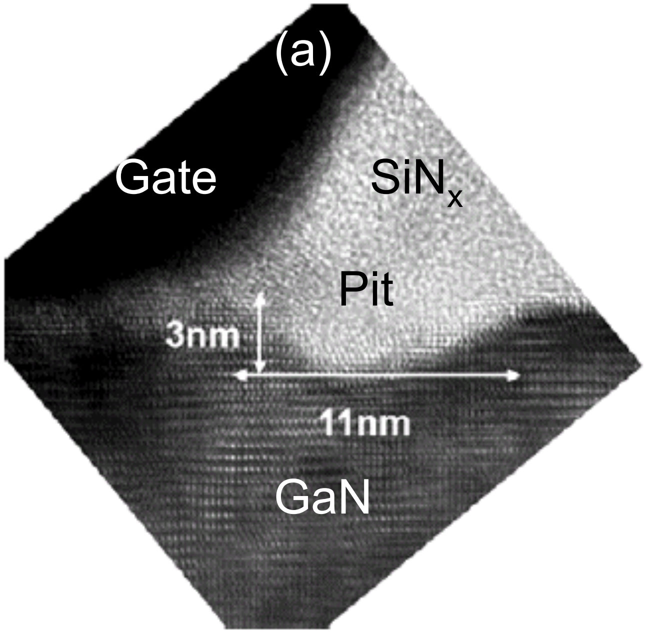
(c)

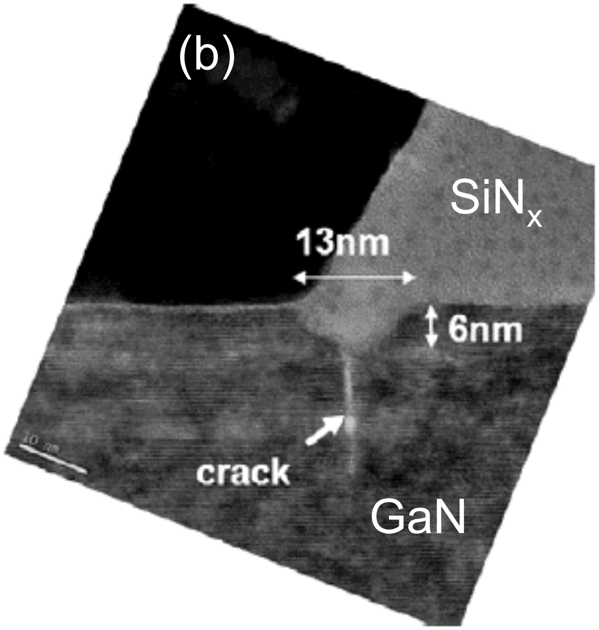
(a) XTEM micrograph of the pit defect
(b) XTEM micrograph of the crack defect
(c) XTEM micrograph of gate metal diffusion into crack defect

C. Chowdhury, et al., IEEE Electron Dev. Lett. 29(10), 1098 (2008)

Previous Studies - Park

- DC testing
  - 1000 hours
  - T_{Ch} = 250°C, 285°C, 320°C
  - V_{DS} = 40 V
  - I_{DQ} = 250 mA/mm



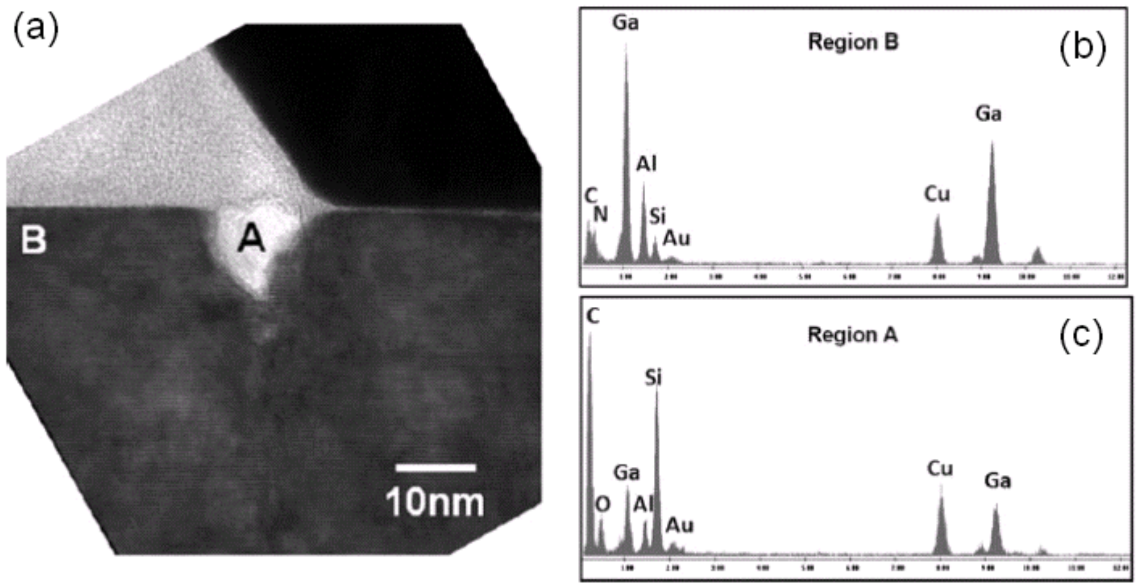


(a) XTEM micrograph of the pit defect
(b) XTEM micrograph of the pit and crack defects

S.Y. Park, et al., Microelectron. Reliab. 49, 478 (2009)

Previous Studies - Park

- Analysis of the reaction product in the pit defect



(a) XTEM micrograph of the reaction product in a pit defect near the gate's drain side
(b) EDS spectrum of a defect free AlGaN/GaN interface
(c) EDS spectrum of the reaction product in the pit defect.

S.Y. Park, et al., Microelectron. Reliab. 49, 478 (2009)

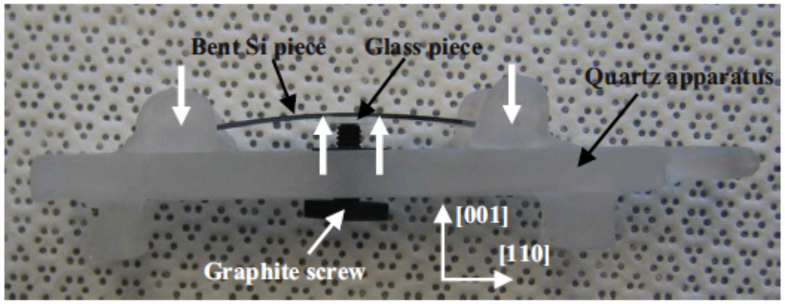
Experiment Setup

- 2 quartz bending jigs
  - One for each wafer thickness
- Wafers cleaved into strips
- Strips are bent
- Strip deflection measured by laser system
  - Measures curvature of strip

$$\frac{1}{r(x)} = \frac{d^2y(x)/dx^2}{\left(1 + (dy(x)/dx)^2\right)^{3/2}}$$

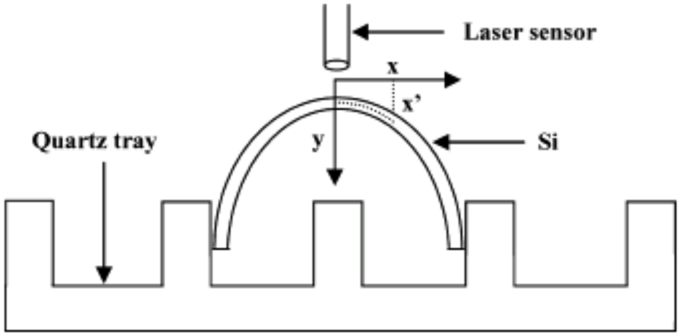
$$\sigma(x) = \frac{E\,c}{r(x)}$$

•Standard



C.R. Olson, et al., J. Vac. Sci. Technol. B, Vol. 24,1, 2006

•Ultra-thin



N.G. Rudawski, et al., Materials Science and Engineering R, Vol. 61, 2008

Future Work

- TEM and LEAP
  - LEAP reconstruction of the Gate/Si/AlGaN gate edge interface
  - TEM micrographs and LEAP reconstructions of stressed and failed devices

- Deprocessing
  - Asher
  - Additional chemical solutions

Conclusions

- Completed the first set of LEAP runs on AlGaN/GaN HEMTS
- Showed the interface layer at the AlGaN/Ni Gate contact region is an oxide
  - involves an Al oxide and Ni Oxide but there does not appear to be any Ga oxide
- Studied the diffusion couple between Gold and Nickel in the gate contact
- Demonstrated the reproducibility of the results
- Next step: apply LEAP to failed devices and to stressed blanket wafer studies